Comment on "Measurement of the Neutron Magnetic Form Factor"

The recent paper by Bruins *et al.* [1] presents data on the neutron magnetic form factor G_{mn} with quoted uncertainties of 2.2%–3.3%. These data were measured in order to achieve a substantial improvement in the knowledge on this fundamental quantity. G_{mn} was measured by quasielastic electron-neutron scattering using the ^{2}H$(e, e'n)$ reaction. The efficiency of the neutron detector employed was measured in a separate experiment using a bremsstrahlung photon beam and the ^{1}H$(\gamma, \pi^+)n$ reaction. Because of two-body kinematics, observation of the π^+ determined the direction and energy of the neutron, and allowed the measurement of the efficiency of the neutron detector, which was placed in this tagged neutron "beam."

This experiment, however, did not employ a pure bremsstrahlung beam [2,3]. The photons were produced by the incident electrons directly in the hydrogen target serving for the ^{1}H$(\gamma, \pi^+)n$ reaction. The thesis of Reike [2] shows that 80% of the detected π^+'s actually originate from *electroproduction* ^{1}H$(e, \pi^+)ne'$. This process has a three-body final state, and reconstruction of the neutron energy and direction from the observation of the π^+ alone is not possible. While a fair part of ^{1}H$(e, \pi^+)ne'$ does lead to electrons with scattering angle $\theta_e < m_e/E_e$—hence kinematics similar to ^{1}H$(\gamma, \pi^+)n$—this is not the case for an important fraction. Bruins *et al.* neglected the contribution of these electroproduced π^+ which do not lead to a neutron in the direction of the neutron detector. The authors base the neglect of π^+ production with angles $\theta_e > m_e/E_e$ on the general dominance of small-angle *inclusive* processes. An estimate for the specific process of *exclusive* ^{1}H$(e, \pi^+)ne'$ for pions of large energy and angle that goes beyond hand-waving arguments, however, requires a quantitative calculation.

The momentum transfer q^2 range and the mean invariant mass W of the kinematics used for the efficiency measurements are listed in Table I. These kinematics are close to an extensive set of π-electroproduction data measured at DESY by Brauel *et al.* [4]. Brauel's data cover the q^2 range 0.06–1.35 (GeV/c)^2 and are measured at W of ~2.2 GeV. As shown and discussed by Brauel, the data are in reasonable agreement to real photoproduction data. We used these data in a Monte Carlo simulation to estimate the fraction $\eta_{\rm miss}$ of pions *without* an associated neutron in the direction of the neutron detector. The same cuts and procedures were used as in the data analysis of Bruins *et al.* This includes the reconstruction of the direction and the energy of the associated neutron from the pion parameters *assuming* photoproduction of the pion. An event was accepted only if the calculated neutron intercepted the nominal central area of the neutron scintillator [5].

TABLE I. Fraction $\eta_{\rm miss}$ of neutrons missing the detector area in the ^{1}H$(e, \pi^+)ne'$ reaction. The kinematics are the ones of Ref. [1].

Label	E MeV	$p^{\pi}_{\rm central}$ MeV/c	Θ^{π} deg	$p^{\pi}_{\rm min}$ MeV/c	q^2 range (GeV/c)^2	W GeV	$\eta_{\rm miss}$ %
I	900	755	23.6	740	0–0.2	1.5	22
II	1600	1381	19.0	1329	0–0.4	1.9	25
III	1600	1294	25.1	1252	0–0.4	1.9	20
IV	1350	972	38.6	919	0–0.2	1.8	13

In order to avoid contributions from double pion production, Bruins *et al.* required the momentum of the detected pion to be larger than a certain value $p^{\pi}_{\rm min}$ [2,3]. This value was estimated using different kinematical assumptions, not calculated from the full two-pion-production kinematics. As the actual values of $p^{\pi}_{\rm min}$ were not recorded, we had to rely on the statement of the authors [5] that the cut employed led to a rejection of about half of the poins detected. With this criterion, we determined the $p^{\pi}_{\rm min}$ values listed in Table I. The error bars of $\eta_{\rm miss}$ are not easily estimated due to the uncertainties cited.

Table I shows that a significant fraction $\eta_{\rm miss}$ of the accepted π^+ corresponds to neutrons that missed the neutron detector. To first order this effect can be corrected by multiplying the measured neutron detection efficiencies with the factor $(1 - f\eta_{\rm miss})^{-1}$, where f, the fraction of electroproduced π^+, is close to a constant for the kinematics used. Neglecting the correction, as done in Ref. [1], leads to an underestimate of the neutron detection efficiency, an overestimate of the electron-neutron cross section by the same amount, and, consequently, to erroneous values for G$_{mn}$

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